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Derivation of cardiac output and alveolar ventilation rate based on energy expenditure measurements in healthy males and females

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ABSTRACT: Physiologically based pharmacokinetic modeling and occupational exposure assessment studies often use minute ventilation rates (*VE*), alveolar ventilation rates (*VA*) and cardiac outputs (*Q*) that are not reflective of the physiological variations encountered during the aggregate daytime activities of individuals from childhood to adulthood. These variations of *VE*, *VA* and *Q* values were determined for healthy normal-weight individuals aged 5–96 years by using two types of published individual data that were measured in the same subjects ($n = 902$), namely indirect calorimetry measurements and the disappearance rates of oral doses of deuterium (^2H) and heavy-oxygen (^{18}O) in urine monitored by gas-isotope-ratio mass spectrometry. Arteriovenous oxygen content differences (0.051–0.082 ml of O_2 consumed ml^{-1} of blood) and ratios of the physiological dead space to the tidal volume (0.232–0.419) were determined for oxygen consumption rates (0.157–0.806 l min^{-1}) required by minute energy expenditures ranging from 0.76 to 3.91 kcal min^{-1}. Generally higher values for the 2.5th up to the 99th percentile for *VE* (0.132–0.774 l kg^{-1} min^{-1}, 4.42–21.69 l m^{-2} min^{-1}), *VA* (0.093–0.553 l kg^{-1} min^{-1}, 3.09–15.53 l m^{-2} min^{-1}), *Q* (0.065–0.330 l kg^{-1} min^{-1}, 2.17 to 9.46 l m^{-2} min^{-1}) and ventilation–perfusion ratios (1.12–2.16) were found in children and teenagers aged 5–<16.5 years compared with older individuals. The distributions of cardiopulmonary parameters developed in this study should be useful in facilitating a scientifically sound characterization of the inter-individual differences in the uptake and health risks of lipophilic air pollutants, particularly as they relate to younger children. Copyright © 2011 John Wiley & Sons, Ltd.

Keywords: minute energy expenditure; oxygen consumption; minute ventilation; alveolar ventilation; physiological dead space; tidal volume; arteriovenous oxygen content difference; cardiac output; blood flow; ventilation–perfusion ratio; health risk assessment

INTRODUCTION

In previous publications (Brochu *et al.*, 2006a–c, 2011) we have developed a methodology for the determination of physiological daily inhalation rates of free-living individuals integrating both night-time and daytime respiratory parameters, namely oxygen uptake factors (*H*) and ventilatory equivalents (*VQ*). This approach was based on published input measurements of oxygen consumption rate (VO_2), carbon dioxide production (VCO_2) and minute ventilation rate (*VE*) in a large number of human subjects in order to determine not only the central values but also the standard deviations of *H* and *VQ* values. The latter values were then integrated with basal daily energy expenditures (BEE) and total daily energy expenditures (TDEE), that are systematically measured using the doubly labeled water method (DLW), into the calculation process of means and distribution percentiles of physiological daily inhalation rates. This method takes into account voluntary and involuntary energy expended in unrestrained free-living subjects during the entire day (i.e. 24 h), on a daily basis during 7–21 days and only requires periodic body fluid samples (usually urine or saliva) for spectrometric measurements of disappearance rates of oral doses of water isotopes (International Dietary Energy Consultancy Group, 1990).

Physiologically based pharmacokinetic (PBPK) simulation studies allow the determination of the internal dose of xenobiotics. In the case of airborne pollutants, PBPK models require, in addition to many other input parameters, cardiac output and alveolar ventilation rate (Krishnan and Andersen, 2001). PBPK modeling and occupational exposure assessment studies would benefit from the use of values of *VE*, alveolar ventilation rate (*VA*) and cardiac output (*Q*) that are reflective of the physiological variations encountered during the aggregate daytime activities over an entire 24 h period, as well as the statistical distribution specific to a group of individuals. For example, the *VE* value of 20.83 l min^{-1}, currently used for occupational exposure assessments, is based on the assumption that workers inhale 10 m^3 in an 8 h workday (US Environmental Protection Agency, 1992). Values for *VA* (3.83–5.87 l min^{-1}) and *Q* (4.04 to 6.73 l min^{-1}) usually used during PBPK simulation

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studies are those for subjects at rest (Arms and Travis, 1988; US Environmental Protection Agency, 1988; Travis and Hattemer-Frey, 1991; Krishnan and Andersen, 2001; Price *et al.*, 2003; Haddad *et al.*, 2006; Valcke and Krishnan, 2009). Finally, despite the fact that variations of minute energy expenditures (*E*) and VO_2 values as a function of time and age are essential for the adequate understanding of the human physiology (Durnin and Passmore, 1967; Elia, 1992, 1997), the distributions of *E* and VO_2 percentiles have never been determined from childhood to adulthood. Overall, this may represent a serious shortcoming when establishing indoor or outdoor hygienic standards for airborne toxic chemicals.

The present study is therefore intended to determine the distribution percentiles for *E*, VO_2, *VE*, *Q* and *VA* as a function of age for healthy normal-weight individuals aged 5–96 years during their aggregate daytime activities. In this process, we also developed equations in terms of *H*, *VQ*, BEE and TDEE values for converting energy expenditure data into those relevant respiratory and cardiovascular parameters.

METHODOLOGY

Study Design

Published BEE and TDEE values measured in the same healthy normal-weight individuals aged 5–96 years ($n = 902$) by indirect calorimetry and DLW measurements respectively and taken from the database reported in Institute of Medicine (2002) were converted into *E*, VO_2, *VE*, *Q*, and *VA* values corresponding to their aggregate daytime activities (referred to as *a*). This was done using six types of preliminary parameters integrated into various physiological equations. These include daily energy costs for growth (ECG), sleep duration, the oxygen uptake factor during postprandial phase (H_P), arteriovenous oxygen content difference (AVOD*a*), ventilatory equivalents (*VQa*) as well as the ratios of physiological dead space to tidal volume (VD_{physa}/VTa ratios, unitless). Values for BEE, TDEE, ECG, sleep duration, H_P and *VQa* as well as body weights and heights of subjects per age group are reported in Brochu *et al.* (2011), while values for AVOD*a* and VD_{physa}/VTa ratios were determined in the present paper. For comparison purposes, *VAa*/Q*a* ratios (unitless) were calculated by using the resulting *VAa* and Q*a* values. Values for *Ea*, VO_2a, *VEa*, Q*a* and *VAa* were also expressed per unit of body weight and body surface area (BSA in m^2). BSA values were calculated using the formula developed by Mosteller (1987) based on height (cm) and body weight (Bw in kg) values:

$$\mathrm{BSA} = \left[\frac{\mathrm{height} \times \mathrm{Bw}}{3600}\right]^{0.5} \tag{1}$$

Some AVOD*a* values and VD_{physa}/VTa ratios were directly obtained from the literature, but most of them were calculated using published sets of Q*a*, VO_2a and VD_{physa},*VTa* measurements. In Brochu *et al.* (2011), it was estimated that the oxygenation during aggregate daytime activities (VO_2a^*) of males and females aged 5–96 years ranged from 0.18–0.81 and 0.16–0.73 l $\min^{-1}$, respectively. Such spans for VO_2a^* values were used for the adequate selection of input data from the literature. Thus, after the classification of data according to age group, solely the published AVOD*a*, Q*a*, VD_{physa} and *VTa* values and the VD_{physa}/VTa ratios measured in subjects with experimental VO_2 demands that were within the span of VO_2a^* values were included in the present study. These subjects were at rest, in either the sitting or standing position, or performing various activities in the upright position such as exercising on a bicycle ergometer, walking or running on a treadmill or, on a few occasions, performing muscular activities. All published values used in this study were measured at sea level in healthy sedentary untrained and trained individuals with no history of respiratory or cardiac problems when breathing an oxygen concentration of 21%. Data for athletes and explorers were excluded from the calculation process of *E*, VO_2, *VE*, *Q* and *VA* values. Note that children and teenagers are hereafter referred to collectively as children.

Procedures for Energetic Measurements

The theoretical basis of indirect calorimetry is explained in Ferrannini (1988) and Bursztein *et al.* (1989), while the DLW procedure is discussed at length in International Dietary Energy Consultancy Group (1990). Indirect calorimetry is the most accurate method (Turell and Alexander, 1964) for determining BEE values based on the equation developed by Weir (1949), where gas exchange (i.e. VCO_2 and VO_2 in l $\min^{-1}$) is monitored and nitrogen excretion from urine is measured (N in g) in subjects at rest. Values for VO_2 and VCO_2 measured by indirect calorimetry have also been used for the determination of H_P value by Brochu *et al.* (2011). On the other hand, the DLW method measures the disappearance rates of predetermined oral doses of doubly labeled water (^2H_2O and $H_2{}^{18}O$) in free-living subjects, deuterium (^2H) and heavy oxygen-18 (^{18}O) being monitored in saliva, blood or urine samples by gas-isotope-ratio mass spectrometry over a period of 7–21 consecutive days. Portions of ingested oral doses of ^2H and ^{18}O react with CO_2 to form isotopic carbonic acid which is rapidly transformed into isotopic bicarbonate ions ($^2HCO_3^-$ and $HC^{18}OO_2^-$) with the catalytic action of carbonic anhydrase. These ions leave erythrocytes to be carried out in the plasma up to the alveolar area. The reverse transformation then occurs in red blood cells where all the ^2H from the $^2HCO_3^-$ returns to isotopic water molecules (^2H_2O), while ^{18}O is returned to the $H_2{}^{18}O$; some also participate in the formation of isotopic carbon dioxide molecules ($C^{18}O_2$). It is therefore a mixture of non-isotopic (CO_2) and isotopic ($C^{18}O_2$) carbon dioxide that is exhaled. The disappearance rate of ^2H reflects water output, while that of ^{18}O represents water output as well as VCO_2 rates. Differences between the two disappearance rates can therefore be used to calculate the VCO_2 rate which is converted into TDEE values (International Dietary Energy Consultancy Group, 1990).

Accuracy of Energetic Measurements

Indirect calorimetry measurements of energy expenditure values are accurate within 0.6–0.7% by comparison with those measured by steady-state direct calorimetry in a sealed chamber (or calorimeter) when urinary nitrogen excretions are considered in order to take into account the metabolism of proteins (Turell and Alexander, 1964). However, as do most investigators, the present study avoids the cumbersome correction for the protein metabolism and accepts an error on BEE values varying from +1 to +2% (Turell and Alexander, 1964) and consequently an error ranging from −2 to −1% on the H_P value (Brochu *et al.*, 2011). As explained by Brochu *et al.* (2011), the mean precision of TDEE and ECG values varies from −1.0

to +3.3%. Therefore, the combined effects of, on the one hand, simultaneous mean errors associated with H_P (i.e. −2 to −1%), BEE (i.e. +1 to +2%), TDEE and ECG (i.e. −1.0 to +3.3%) values on, on the other hand, values of VO_2a, Qa, VEa, VAa were determined in the present study.

Ea, VO_2a and *VEa* Values

Precise values for VO_2a compared with VO_2a^* (l min^{-1}) were calculated in this study as well as minute energy expenditures (*Ea* in kcal min^{-1}) and *VEa* values (l min^{-1}). According to Brochu *et al.* (2011), these values can be expressed in terms of BEE, TDEE, ECG (kcal per day) and sleep duration (Sld in h per day) values by using the following equations:

$$Ea = \left[\frac{\text{TDEE}-\text{BEE}}{(24-\text{Sld})\times 60}\right] + \left[\frac{\text{BEE}+\text{ECG}}{1440}\right] \tag{2}$$

$$VO_2a = \left[\frac{(\text{TDEE}-\text{BEE})}{(24-\text{Sld})\times 60} + \frac{(\text{BEE}+\text{ECG})}{1440}\right] \times H_P \tag{3}$$

$$VEa = \left[\frac{(\text{TDEE}-\text{BEE})}{(24-\text{Sld})\times 60} + \frac{(\text{BEE}+\text{ECG})}{1440}\right] \times H_P \times VQa \tag{4}$$

where 1440 and 60 are the conversion factors from days to minutes and hours to minutes, respectively, and 24 is the number of hours in a day.

The value for ECG must be added to BEE in order to take into account the energy requirements for the growth process from birth to adulthood (Brochu *et al.*, 2006a). H_P is the volume of oxygen consumed (at standard temperature and pressure, dry air, STPD) to produce 1 kcal of energy expended during the postprandial phase. *VQa* is the ratio of the *VEa* value (at body temperature and saturated with water vapour, BTPS) to the VO_2a value (at standard temperature and pressure, dry air, STPD), or VEa/VO_2a ratio (unitless). The value for H_P of 0.2059 ± 0.0019 l of O_2 kcal^{-1} ($n = 1245$) and *VQa* values varying from 29.9 ± 4.2 to 32.9 ± 6.4 ($n = 826$) according to age group were obtained from Brochu *et al.* (2011).

Q Values

The Fick principle (Fick, 1870) is one of the cornerstones of human cardiovascular physiology. The physiological mass balance between whole body VO_2a (l min^{-1}), Qa (l min^{-1}) and the arterial (CaO_2) and mixed venous (CvO_2) blood oxygen contents (ml of O_2 ml^{-1} of blood), is outlined by the eponymous Fick principle as follows:

$$VO_2a = Qa \times (CaO_2 - CvO_2) = Qa \times \text{AVOD}a \tag{5}$$

where AVOD*a* = O_2 extraction (i.e. arteriovenous oxygen content difference). Therefore,

$$Qa = \left[\frac{(\text{TDEE}-\text{BEE})}{(24-\text{Sld})\times 60} + \frac{(\text{BEE}+\text{ECG})}{1440}\right] \times \frac{H_P}{\text{AVOD}a} \tag{6}$$

VA Values

Values for VD_{phys} (Bohr, 1891; Enghoff, 1938) include volumes of the conducting airway referred to as anatomical dead space (Fowler, 1948; Folkow and Pappenheimer, 1955) and some underperfused alveoli (known as the alveolar dead space) not contributing to gas exchange (Guyton, 1991). The *VA* is defined as the fraction of the inspired tidal volume per minute (*VT* multiplied by the respiratory frequency, known as the f value) which participates in gas exchange (Guyton, 1991). The *VAa* (l min^{-1}) is related to the *VTa* (l), VD_{physa} (l), *f* (number of breaths per minute) and *VEa* (l min^{-1}) values by the following equations (Guyton, 1991):

$$VAa = (VTa - VD_{physa}) \times fa \tag{7}$$

$$VAa = VEa \times \left[1 - \frac{VD_{physa}}{VTa}\right] \tag{8}$$

Therefore, *VAa* in this study was computed as follows:

$$VAa = \left[\frac{(\text{TDEE}-\text{BEE})}{(24-\text{Sld})\times 60} + \frac{(\text{BEE}+\text{ECG})}{1440}\right] \times \left[1 - \frac{VD_{physa}}{VTa}\right] \times H_P \times VQa \tag{9}$$

Sleep Duration

Values for sleep duration in individuals aged 5–96 years ($n = 13\,371$) taken from Brochu *et al.* (2011) were used in the present study regardless of the proportions of under-, normal-weight, overweight and obese individuals in the cohorts. As showed in Brochu *et al.* (2011), several publications have reported a correlation between sleep curtailment and a higher body mass index (BMI) in children and adults, while others are challenging the view that sleep duration in subjects is inversely related to BMI increases. Therefore, the influence of shorter sleep duration of overweight and obese subjects on the order of magnitude of VO_2a, Qa, VEa, VAa values and VA/Qa ratios was determined using the calculation process developed by Brochu *et al.* (2011). A first set of data was calculated by using sleep duration reported for a cohort of children aged 7.5–16.5 years (Eisenmann *et al.*, 2006; $n = 3410$) and another of adults 35–74.5 years (Bernsteins *et al.*, 2001; $n = 6324$) for which the proportions of normal-weight, overweight and obese individuals were known. These data were then compared with a second set of values that was calculated when initial sleep durations for 60% of overweight/obese children, and 35% of overweight as well as 55% of obese adults were decreased by 25%. This calculation corresponds to the worst case scenario of sleep duration decrease associated with overweight and obese individuals according to current literature. Further information regarding such a calculation scenario is presented in Brochu *et al.* (2011).

Statistical Analysis

The best fit distributions (i.e. log–normal or normal) for TDEE, BEE, ECG, sleep duration, body weight, BSA, H_P and *VQa* values have been presented in Brochu *et al.* (2011). Anderson–Darling goodness-of-fit tests were carried out on individual *Qa*, AVOD*a* and *VAa* values, as well as VD_{physa}/VTa ratios from the literature in order to determine their best fit distribution (Cook *et al.*, 1955; Stahlman and Meece, 1957; Johnson *et al.*, 1960; Reeves *et al.*, 1961; Becklake *et al.*, 1962; Donevan *et al.*, 1962; Nelson *et al.*, 1962; Åstrand *et al.*, 1964; Frick and

Somer, 1964; Tabakin *et al.*, 1964; Beaudry *et al.*, 1966; Damato *et al.*, 1966; Ekblom *et al.*, 1968; Ouellet *et al.*, 1969; Hermansen *et al.*, 1970; Jones *et al.*, 1970; Pernow and Saltin, 1971; Frostell *et al.*, 1983; Torre-Bueno *et al.*, 1985).

Means, standard deviations (SD) and distribution percentiles were calculated for AVOD*α*, *Eα*, $VO_2α$, Q*α*, *VEα* and *VAα* values as well as $VD_{physα}/VTα$ and *VA*/Q*α* ratios. Monte Carlo simulations were conducted based on random sampling involving 10 000 iterations for each calculation process. Distributions were truncated at the minimal and maximal observed values based on a critical analysis of the data compiled from an exhaustive review of the literature. This was done to eliminate from Monte Carlo simulations any outliers that did not remain within the bounds of physiological constraints.

RESULTS

Mean and SD values as well as distribution percentiles of AVOD*α*, $VD_{physα}/VTα$, *Eα*, $VO_2α$, *VEα*, Q*α*, *VAα* and *VAα*/Q*α* for subjects aged 5–96 years are reported in Tables 1–8 respectively. Mean values as a function of age for *Eα* and $VO_2α$, as well as those for *VEα*, Q*α* and *VAα* are presented in Figures 1–3 and 4–6, respectively. Compared with rates expressed per unit of body surface area, those expressed per unit of body weight gradually decrease with age: values for Q*α* are reduced by 45 and 50%, respectively, while *Eα*, $VO_2α$, *VEα*, *VAα* decrease by 51–59% from 5–96 years (Tables 3–7).

Individual Q*α* ($n = 129$) and AVOD*α* ($n = 129$) values were found to have a better fit with log–normal distributions according to Anderson–Darling goodness-of-fit tests, compared with

Table 1. Distribution percentiles of arterioveinous oxygen content differences for aggregate daytime activities of healthy individuals aged 5–96 years

Age group for both gender (years)	*n*	Mean ± SD	Min	Max	2.5nd	10th	25th	50th	75th	90th	97.5th	99th
		Arteriovenous oxygen content differences[a] (ml of O_2 consumed/ml of blood)			Percentiles[b]							
5 to <16.5	110	0.073 ± 0.004	0.057	0.088	0.065	0.067	0.070	0.073	0.075	0.078	0.081	0.082
16.5 to <25	286	0.060 ± 0.005	0.049	0.076	0.051	0.054	0.056	0.060	0.063	0.066	0.070	0.072
25 to <45	193	0.062 ± 0.004	0.048	0.078	0.054	0.057	0.059	0.062	0.064	0.067	0.070	0.072
45 to ≤96	30	0.059 ± 0.003	0.051	0.069	0.054	0.056	0.057	0.059	0.061	0.063	0.065	0.066

[a]Measurements reported in Johnson *et al.* (1960), Reeves *et al.* (1961), Donevan *et al.* (1962), Åstrand *et al.* (1964), Frick and Somer (1964), Tabakin *et al.* (1964), Dagenais *et al.* (1966), Damato *et al.* (1966), Ekblom *et al.* (1968), Ouellet *et al.* (1969), Hermansen *et al.* (1970), Jones *et al.* (1970), Eriksson *et al.* (1971), Pernow and Saltin (1971), Krone *et al.* (1972), Zeidifard *et al.* (1972), Sharma *et al.* (1977), Kanstrup and Ekblom (1978), Hossack and Bruce (1982), Frostell *et al.* (1983), Lewis *et al.* (1983), Torre-Bueno *et al.* (1985), Wagner *et al.* (1986), Bebout *et al.* (1989), Miyamoto *et al.* (1989), Podolsky *et al.* (1996), Turley and Wilmore (1997a), Rice *et al.* (1999), Hopkins *et al.* (2000), Sun *et al.* (2000), McGuire *et al.* (2001), Nottin *et al.* (2002), Poole *et al.* (2002), Vinet *et al.* (2002), Gisolf *et al.* (2003), Olfert *et al.* (2004), Dibski *et al.* (2005). [b]Percentiles based on a log–normal distribution according to the Anderson–Darling test performed on individual data. *n* = number of individuals; SD = standard deviation; Min = minimum; Max = maximum.

Table 2. Distribution percentiles of ratios of physiological dead space to tidal volume for aggregate daytime activities of healthy individuals aged 5–96 years

Age group for both gender (years)	*n*	Mean ± SD	Min	Max	2.5nd	10th	25th	50th	75th	90th	97.5th	99th
		Ratios of physiological dead space to tidal volume[a] (unitless)			Percentiles[b]							
5 to <10[c]	52	0.336 ± 0.040	0.244	0.428	0.264	0.287	0.311	0.337	0.363	0.398	0.409	0.418
10 to <16.5[d]	81	0.294 ± 0.032	0.203	0.386	0.232	0.253	0.272	0.293	0.315	0.345	0.357	0.366
16.5 to <25[e]	48	0.301 ± 0.026	0.220	0.386	0.250	0.268	0.283	0.300	0.318	0.343	0.351	0.361
25 to <35[f]	112	0.329 ± 0.015	0.280	0.389	0.299	0.310	0.319	0.329	0.339	0.354	0.359	0.364
35 to <45[g]	79	0.344 ± 0.018	0.281	0.407	0.308	0.321	0.331	0.344	0.356	0.374	0.380	0.386
45 to <65[h]	55	0.339 ± 0.021	0.273	0.405	0.299	0.312	0.325	0.340	0.354	0.374	0.380	0.388
65 to ≤96[i]	36	0.381 ± 0.018	0.334	0.428	0.347	0.359	0.369	0.382	0.393	0.410	0.414	0.419

[a]*VD*physα/*VT*α ratios. [b]Percentiles based on a normal distribution according to the Anderson–Darling test performed on individual data. [c]Kerr (1976). [d]Beaudry *et al.* (1966) and Kerr (1976).[e]Mellemgaard (1966), Whipp and Wasserman (1969), Olfert *et al.* (2004). [f]Froeb (1962), Malmberg (1966), Mellemgaard (1966), Whipp and Wasserman (1969), Craig *et al.* (1971), Frostell *et al.* (1983), Allen *et al.* (1984), Dempsey *et al.* (1984), Olfert *et al.* (2004). [g]Froeb (1962), Malmberg (1966), Mellemgaard (1966), Craig *et al.* (1971), Dempsey *et al.* (1984). [h]Mellemgaard (1966), Craig *et al.* (1971), Frostell *et al.* (1983). [i]Tenney and Miller (1956), Mellemgaard (1966), Craig *et al.* (1971). *n* = number of individuals; SD = standard deviation; Min = minimum; Max = maximum.

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Table 3. Distribution percentiles of minute energy expenditures for aggregate daytime activities of normal-weight individuals aged 5–96 years

Age group (years)	Minute energy expenditures[a] Males Mean ± SD	Males Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th	Females Mean ± SD	Females Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th
									(kcal min^{-1})									
5 to <7	1.22 ± 0.24	0.81	0.92	1.05	1.21	1.37	1.54	1.75	1.85	1.18 ± 0.22	0.79	0.89	1.01	1.16	1.32	1.48	1.66	1.75
7 to <10	1.54 ± 0.36	0.96	1.10	1.27	1.50	1.76	2.03	2.36	2.54	1.48 ± 0.31	0.97	1.11	1.26	1.46	1.68	1.90	2.17	2.29
10 to <16.5	2.27 ± 0.63	1.29	1.50	1.78	2.18	2.68	3.16	3.70	3.91	1.93 ± 0.50	1.12	1.32	1.56	1.87	2.25	2.61	3.05	3.32
16.5 to <25	2.68 ± 0.45	1.83	2.07	2.35	2.69	3.02	3.27	3.49	3.64	2.22 ± 0.32	1.62	1.81	2.00	2.21	2.44	2.63	2.86	2.97
25 to <35	2.55 ± 0.48	1.77	1.97	2.20	2.50	2.85	3.20	3.63	3.86	2.06 ± 0.41	1.36	1.56	1.76	2.03	2.32	2.60	2.96	3.15
35 to <45	2.49 ± 0.33	1.92	2.07	2.24	2.48	2.72	2.94	3.14	3.23	2.08 ± 0.29	1.56	1.69	1.85	2.07	2.29	2.47	2.64	2.71
45 to <65	2.25 ± 0.42	1.57	1.72	1.93	2.20	2.54	2.84	3.15	3.27	1.82 ± 0.34	1.17	1.37	1.57	1.81	2.05	2.28	2.52	2.63
65 to ≤96	1.89 ± 0.44	1.14	1.34	1.57	1.86	2.19	2.50	2.84	2.97	1.41 ± 0.39	0.76	0.92	1.12	1.37	1.65	1.96	2.27	2.39
									(kcal kg^{-1} min^{-1})[b]									
5 to <7	0.063 ± 0.014	0.040	0.046	0.053	0.061	0.071	0.081	0.093	0.101	0.061 ± 0.013	0.038	0.044	0.051	0.059	0.069	0.079	0.090	0.097
7 to <10	0.059 ± 0.017	0.033	0.040	0.047	0.057	0.068	0.082	0.098	0.108	0.055 ± 0.013	0.033	0.039	0.045	0.053	0.063	0.073	0.084	0.091
10 to <16.5	0.055 ± 0.020	0.026	0.033	0.040	0.052	0.067	0.083	0.103	0.116	0.044 ± 0.014	0.023	0.028	0.034	0.042	0.053	0.063	0.078	0.086
16.5 to <25	0.038 ± 0.007	0.025	0.029	0.033	0.038	0.043	0.047	0.052	0.055	0.037 ± 0.006	0.026	0.029	0.033	0.037	0.041	0.045	0.050	0.053
25 to <35	0.036 ± 0.008	0.024	0.027	0.031	0.035	0.040	0.046	0.053	0.057	0.036 ± 0.008	0.022	0.026	0.030	0.035	0.041	0.046	0.053	0.058
35 to <45	0.036 ± 0.006	0.026	0.029	0.032	0.035	0.039	0.043	0.048	0.050	0.035 ± 0.006	0.026	0.028	0.031	0.035	0.039	0.043	0.047	0.049
45 to <65	0.032 ± 0.007	0.021	0.024	0.027	0.031	0.036	0.041	0.046	0.049	0.031 ± 0.006	0.020	0.023	0.026	0.031	0.035	0.039	0.044	0.047
65 to ≤96	0.028 ± 0.007	0.016	0.019	0.023	0.027	0.032	0.037	0.043	0.046	0.025 ± 0.007	0.013	0.016	0.019	0.024	0.029	0.035	0.042	0.045
									(kcal m^{-2} min^{-1})[b]									
5 to <7	1.56 ± 0.33	1.01	1.16	1.32	1.53	1.76	1.99	2.29	2.43	1.50 ± 0.31	0.97	1.12	1.28	1.48	1.69	1.92	2.18	2.33
7 to <10	1.59 ± 0.41	0.94	1.11	1.29	1.54	1.84	2.15	2.54	2.76	1.50 ± 0.33	0.95	1.10	1.26	1.47	1.71	1.94	2.23	2.38
10 to <16.5	1.72 ± 0.56	0.89	1.07	1.30	1.63	2.04	2.49	3.03	3.29	1.40 ± 0.40	0.76	0.92	1.11	1.35	1.64	1.94	2.29	2.50
16.5 to <25	1.44 ± 0.25	0.97	1.10	1.25	1.43	1.61	1.77	1.93	2.00	1.33 ± 0.20	0.95	1.07	1.18	1.32	1.46	1.59	1.74	1.82
25 to <35	1.36 ± 0.27	0.92	1.04	1.16	1.33	1.52	1.72	1.96	2.10	1.27 ± 0.27	0.81	0.94	1.08	1.25	1.43	1.62	1.85	1.99
35 to <45	1.35 ± 0.19	1.02	1.11	1.21	1.34	1.48	1.61	1.74	1.80	1.27 ± 0.19	0.94	1.02	1.13	1.26	1.40	1.53	1.64	1.70
45 to <65	1.21 ± 0.24	0.82	0.91	1.02	1.18	1.36	1.54	1.71	1.81	1.12 ± 0.22	0.71	0.83	0.96	1.11	1.26	1.41	1.56	1.63
65 to ≤96	1.05 ± 0.25	0.62	0.73	0.86	1.03	1.21	1.39	1.59	1.68	0.88 ± 0.25	0.47	0.58	0.69	0.86	1.04	1.23	1.45	1.56

[a]Ea = [(TDEE − BEE)/((24 − Sld) × 60) + (BEE + ECG)/1440], where TDEE = total daily energy expenditure, BEE = basal energy expenditure and ECG = stored daily energy cost for growth. [b]Ea (kcal min^{-1}) were divided by body weights (Bw) and body surface areas (BSA) in order to obtain values expressed in kcal kg^{-1} min^{-1} and kcal m^{-2} min^{-1}, respectively.
[a, b]Values for TDEE, BEE, ECG (kcal per day), Sld (h per day), Bw (kg) and BSA (m^2) are presented in Brochu *et al.* (2011). SD = standard deviation.

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Table 4. Distribution percentiles of oxygen consumption rates for aggregate daytime activities of normal-weight individuals aged 5–96 years

Age group (years)	Oxygen consumption rates[a]																	
	Males									Females								
	Mean ± SD	Percentiles								Mean ± SD	Percentiles							
		2.5nd	10th	25th	50th	75th	90th	97.5th	99th		2.5nd	10th	25th	50th	75th	90th	97.5th	99th
									(l min^{-1})									
5 to <7	0.252 ± 0.050	0.167	0.189	0.216	0.248	0.283	0.317	0.360	0.381	0.242 ± 0.046	0.163	0.184	0.209	0.238	0.271	0.305	0.341	0.360
7 to <10	0.316 ± 0.075	0.197	0.226	0.261	0.309	0.362	0.417	0.487	0.522	0.305 ± 0.063	0.199	0.229	0.259	0.300	0.345	0.390	0.446	0.472
10 to <16.5	0.466 ± 0.131	0.266	0.310	0.366	0.449	0.551	0.650	0.763	0.806	0.397 ± 0.103	0.229	0.271	0.322	0.386	0.463	0.538	0.628	0.681
16.5 to <25	0.552 ± 0.093	0.376	0.426	0.483	0.553	0.621	0.673	0.720	0.750	0.457 ± 0.065	0.334	0.373	0.412	0.455	0.502	0.542	0.588	0.611
25 to <35	0.526 ± 0.099	0.364	0.406	0.452	0.515	0.586	0.658	0.747	0.796	0.424 ± 0.085	0.280	0.320	0.363	0.418	0.477	0.536	0.610	0.648
35 to <45	0.513 ± 0.067	0.395	0.426	0.462	0.510	0.560	0.605	0.647	0.665	0.428 ± 0.060	0.321	0.349	0.382	0.426	0.471	0.509	0.544	0.559
45 to <65	0.463 ± 0.087	0.323	0.353	0.397	0.453	0.522	0.585	0.648	0.671	0.374 ± 0.071	0.240	0.283	0.324	0.372	0.423	0.469	0.518	0.542
65 to ≤96	0.390 ± 0.091	0.235	0.276	0.323	0.383	0.451	0.515	0.584	0.611	0.290 ± 0.080	0.157	0.190	0.230	0.282	0.340	0.403	0.467	0.494
									(l kg^{-1} min^{-1})[b]									
5 to <7	0.013 ± 0.003	0.008	0.009	0.011	0.013	0.015	0.017	0.019	0.021	0.012 ± 0.003	0.008	0.009	0.010	0.012	0.014	0.016	0.019	0.020
7 to <10	0.012 ± 0.003	0.007	0.008	0.010	0.012	0.014	0.017	0.020	0.022	0.011 ± 0.003	0.007	0.008	0.009	0.011	0.013	0.015	0.017	0.019
10 to <16.5	0.011 ± 0.004	0.005	0.007	0.008	0.011	0.014	0.017	0.021	0.024	0.009 ± 0.003	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.018
16.5 to <25	0.008 ± 0.001	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.011	0.008 ± 0.001	0.005	0.006	0.007	0.008	0.008	0.009	0.010	0.011
25 to <35	0.007 ± 0.002	0.005	0.006	0.006	0.007	0.008	0.009	0.011	0.012	0.007 ± 0.002	0.005	0.005	0.006	0.007	0.008	0.010	0.011	0.012
35 to <45	0.007 ± 0.001	0.005	0.006	0.007	0.007	0.008	0.009	0.010	0.010	0.007 ± 0.001	0.005	0.006	0.006	0.007	0.008	0.009	0.010	0.010
45 to <65	0.007 ± 0.001	0.004	0.005	0.005	0.006	0.007	0.008	0.009	0.010	0.006 ± 0.001	0.004	0.005	0.005	0.006	0.007	0.008	0.009	0.010
65 to ≤96	0.006 ± 0.001	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.005 ± 0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.009
									(l m^{-2} min^{-1})[b]									
5 to <7	0.321 ± 0.067	0.207	0.239	0.272	0.315	0.363	0.411	0.471	0.502	0.309 ± 0.064	0.200	0.230	0.264	0.305	0.349	0.395	0.448	0.480
7 to <10	0.328 ± 0.085	0.195	0.228	0.266	0.318	0.378	0.442	0.521	0.566	0.309 ± 0.068	0.195	0.226	0.260	0.303	0.352	0.400	0.457	0.491
10 to <16.5	0.354 ± 0.115	0.183	0.221	0.267	0.336	0.420	0.512	0.623	0.677	0.288 ± 0.082	0.158	0.190	0.228	0.278	0.338	0.400	0.475	0.517
16.5 to <25	0.296 ± 0.052	0.199	0.227	0.258	0.295	0.332	0.364	0.396	0.412	0.273 ± 0.042	0.195	0.220	0.244	0.271	0.301	0.328	0.359	0.375
25 to <35	0.280 ± 0.055	0.190	0.213	0.239	0.274	0.314	0.355	0.405	0.432	0.261 ± 0.055	0.167	0.194	0.221	0.256	0.295	0.333	0.381	0.409
35 to <45	0.278 ± 0.039	0.210	0.228	0.249	0.276	0.305	0.331	0.358	0.372	0.261 ± 0.038	0.193	0.211	0.232	0.260	0.288	0.314	0.337	0.350
45 to <65	0.248 ± 0.049	0.170	0.188	0.211	0.243	0.281	0.317	0.353	0.373	0.230 ± 0.045	0.146	0.171	0.198	0.228	0.260	0.290	0.322	0.337
65 to ≤96	0.215 ± 0.052	0.128	0.151	0.177	0.211	0.249	0.287	0.328	0.346	0.182 ± 0.052	0.097	0.119	0.143	0.176	0.215	0.254	0.299	0.321

[a]$VO_2\alpha = [(TDEE - BEE)/((24 - Sld) \times 60) + (BEE + ECG)/1440] \times H_P$, where H_p = oxygen uptake factor. TDEE, BEE, ECG and Sld are defined in Table 3. [b]$VO_2\alpha$ (L min^{-1}) were divided by body weights (Bw) and body surface areas (BSA) in order to obtain values expressed in l kg^{-1} min^{-1} and l m^{-2} min^{-1}, respectively. [a, b]Values for TDEE, BEE, ECG (kcal per day), Sld (h per day), Bw (kg), BSA (m^2) and HP (0.2059 ± 0.0019 l of O_2 kcal^{-1}) are reported in Brochu *et al.* (2011). SD = standard deviation.

Table 5. Distribution percentiles of minute ventilation rates for aggregate daytime activities of normal-weight individuals aged 5–96 years

Age group (years)	Minute ventilation rates[a] Males Mean ± SD	Males Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th	Females Mean ± SD	Females Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th
									(l min^{-1})									
5 to <7	7.75 ± 1.55	5.10	5.82	6.63	7.64	8.75	9.78	11.10	11.84	7.45 ± 1.44	4.99	5.65	6.41	7.32	8.36	9.39	10.56	11.20
7 to <10	9.74 ± 2.32	6.01	6.94	8.02	9.50	11.15	12.91	15.01	16.17	9.40 ± 1.96	6.10	7.00	7.98	9.22	10.64	12.06	13.75	14.62
10 to <16.5	13.94 ± 4.42	7.28	8.82	10.68	13.25	16.52	20.07	24.20	26.51	11.87 ± 3.55	6.33	7.70	9.27	11.40	13.98	16.65	20.09	22.00
16.5 to <25	17.91 ± 4.54	10.63	12.51	14.61	17.35	20.63	24.10	28.04	30.41	14.83 ± 3.48	9.22	10.73	12.33	14.40	16.91	19.45	22.66	24.50
25 to <35	17.17 ± 4.12	10.69	12.34	14.19	16.64	19.64	22.69	26.57	29.04	13.86 ± 3.43	8.20	9.82	11.42	13.51	15.84	18.44	21.73	23.46
35 to <45	16.95 ± 4.94	9.42	11.25	13.39	16.20	19.83	23.55	28.27	31.39	14.15 ± 4.26	7.69	9.28	11.07	13.52	16.60	19.90	23.94	26.87
45 to <65	15.47 ± 4.40	8.64	10.41	12.29	14.86	17.95	21.39	25.77	28.06	12.51 ± 3.59	6.78	8.30	9.91	12.08	14.62	17.29	20.72	22.71
65 to ≤96	13.05 ± 4.17	6.55	8.23	10.03	12.45	15.41	18.63	22.95	25.16	9.69 ± 3.43	4.52	5.72	7.16	9.14	11.65	14.38	17.72	19.64
									(l kg^{-1} min^{-1})[b]									
5 to <7	0.397 ± 0.089	0.249	0.289	0.333	0.389	0.450	0.515	0.592	0.645	0.383 ± 0.086	0.241	0.280	0.322	0.375	0.436	0.500	0.573	0.616
7 to <10	0.374 ± 0.107	0.209	0.251	0.296	0.359	0.435	0.520	0.623	0.693	0.348 ± 0.084	0.209	0.246	0.286	0.339	0.400	0.460	0.539	0.582
10 to <16.5	0.341 ± 0.135	0.151	0.193	0.242	0.316	0.413	0.517	0.675	0.774	0.273 ± 0.096	0.132	0.166	0.203	0.259	0.324	0.402	0.505	0.553
16.5 to <25	0.255 ± 0.068	0.148	0.175	0.205	0.246	0.295	0.347	0.412	0.442	0.248 ± 0.062	0.149	0.175	0.203	0.240	0.284	0.331	0.391	0.426
25 to <35	0.242 ± 0.062	0.145	0.170	0.197	0.233	0.279	0.325	0.386	0.422	0.240 ± 0.065	0.137	0.163	0.193	0.231	0.277	0.325	0.387	0.424
35 to <45	0.244 ± 0.074	0.132	0.159	0.191	0.232	0.286	0.343	0.415	0.455	0.242 ± 0.076	0.128	0.157	0.187	0.230	0.284	0.344	0.413	0.461
45 to <65	0.217 ± 0.065	0.118	0.143	0.170	0.208	0.254	0.303	0.372	0.414	0.214 ± 0.063	0.114	0.140	0.168	0.206	0.251	0.299	0.357	0.399
65 to ≤96	0.193 ± 0.064	0.096	0.119	0.146	0.184	0.227	0.278	0.349	0.385	0.171 ± 0.064	0.076	0.098	0.124	0.161	0.206	0.257	0.322	0.356
									(l m^{-2} min^{-1})[b]									
5 to <7	9.88 ± 2.10	6.35	7.34	8.37	9.68	11.21	12.61	14.54	15.57	9.53 ± 1.98	6.18	7.08	8.11	9.34	10.75	12.17	13.87	14.86
7 to <10	10.10 ± 2.62	5.91	6.99	8.19	9.78	11.65	13.64	16.12	17.54	9.51 ± 2.12	5.97	6.97	7.98	9.32	10.85	12.36	14.17	15.15
10 to <16.5	10.56 ± 3.77	5.04	6.28	7.78	9.95	12.67	15.65	19.53	21.69	8.61 ± 2.76	4.42	5.43	6.57	8.19	10.21	12.28	15.05	16.64
16.5 to <25	9.60 ± 2.49	5.58	6.68	7.79	9.28	11.09	12.90	15.21	16.54	8.85 ± 2.13	5.42	6.34	7.29	8.62	10.15	11.72	13.61	14.82
25 to <35	9.15 ± 2.27	5.56	6.49	7.51	8.84	10.49	12.14	14.36	15.77	8.52 ± 2.19	4.95	5.96	6.95	8.29	9.78	11.42	13.41	14.81
35 to <45	9.19 ± 2.71	5.07	6.06	7.22	8.78	10.72	12.83	15.55	16.99	8.64 ± 2.63	4.62	5.65	6.73	8.26	10.14	12.19	14.63	16.36
45 to <65	8.30 ± 2.41	4.61	5.50	6.55	7.97	9.66	11.52	13.91	15.46	7.68 ± 2.23	4.12	5.08	6.07	7.40	9.00	10.62	12.87	14.10
65 to ≤96	7.21 ± 2.35	3.60	4.51	5.50	6.87	8.50	10.36	12.82	14.21	6.08 ± 2.20	2.80	3.54	4.47	5.75	7.32	9.06	11.23	12.52

[a]VEa = [(TDEE − BEE)/((24 − Sld) × 60) + (BEE+ECG)/1440] × H_P × VQa, where Hp = oxygen uptake factor and VQa = ventilatory equivalent. TDEE, BEE, ECG and Sld are defined in Table 3. [b]VEa (l min^{-1}) were divided by body weights (Bw) and body surface areas (BSA) in order to obtain values expressed in l kg^{-1} min^{-1} and l m^{-2} min^{-1} respectively. [a, b]Values for TDEE, BEE, ECG (kcal per day), Sld (h per day), Bw (kg), BSA (m^2), H_P (0.2059 ± 0.0019 l of O_2 kcal^{-1}) and VQa (unitless) are given in Brochu *et al.* (2011). SD = standard deviation.

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Table 6. Distribution percentiles of cardiac outputs for aggregate daytime activities of normal-weight individuals aged 5–96 years

Age group (years)	Cardiac outputs[a] Males Mean ± SD	Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th	Females Mean ± SD	Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th
($l\ min^{-1}$)																		
5 to <7	3.48 ± 0.71	2.28	2.60	2.96	3.42	3.93	4.43	5.04	5.40	3.35 ± 0.66	2.23	2.53	2.86	3.31	3.77	4.23	4.77	5.05
7 to <10	4.35 ± 1.04	2.69	3.10	3.59	4.24	4.98	5.77	6.73	7.22	4.22 ± 0.91	2.70	3.10	3.55	4.13	4.78	5.45	6.23	6.67
10 to <16.5	6.44 ± 1.83	3.61	4.25	5.04	6.18	7.60	9.03	10.52	11.19	5.48 ± 1.45	3.11	3.72	4.41	5.33	6.39	7.45	8.78	9.48
16.5 to <25	9.27 ± 1.71	6.14	7.02	8.01	9.23	10.46	11.53	12.66	13.23	7.68 ± 1.25	5.45	6.11	6.79	7.61	8.51	9.32	10.28	10.87
25 to <35	8.56 ± 1.71	5.80	6.50	7.29	8.38	9.59	10.86	12.40	13.19	6.91 ± 1.46	4.43	5.13	5.88	6.79	7.79	8.84	10.12	10.89
35 to <45	8.35 ± 1.22	6.21	6.81	7.44	8.28	9.17	10.02	10.89	11.35	6.97 ± 1.08	5.07	5.59	6.17	6.91	7.70	8.40	9.17	9.55
45 to <65	7.85 ± 1.51	5.39	5.96	6.71	7.68	8.84	9.97	11.08	11.65	6.34 ± 1.24	4.02	4.75	5.47	6.31	7.17	7.99	8.89	9.34
65 to ≤96	6.61 ± 1.57	3.95	4.67	5.43	6.48	7.66	8.79	9.96	10.54	4.91 ± 1.39	2.64	3.21	3.89	4.75	5.78	6.84	8.01	8.52
($l\ kg^{-1}\ min^{-1}$)[b]																		
5 to <7	0.178 ± 0.041	0.111	0.129	0.149	0.174	0.203	0.233	0.269	0.290	0.172 ± 0.039	0.107	0.125	0.143	0.168	0.196	0.223	0.258	0.279
7 to <10	0.167 ± 0.048	0.094	0.112	0.133	0.161	0.194	0.231	0.276	0.305	0.155 ± 0.039	0.092	0.109	0.127	0.151	0.179	0.208	0.244	0.263
10 to <16.5	0.157 ± 0.058	0.073	0.092	0.115	0.148	0.190	0.237	0.296	0.330	0.126 ± 0.040	0.065	0.079	0.096	0.120	0.149	0.179	0.223	0.247
16.5 to <25	0.132 ± 0.027	0.085	0.098	0.113	0.131	0.149	0.167	0.188	0.199	0.128 ± 0.024	0.087	0.099	0.112	0.127	0.143	0.159	0.180	0.192
25 to <35	0.121 ± 0.027	0.078	0.090	0.101	0.117	0.136	0.156	0.180	0.194	0.120 ± 0.029	0.073	0.085	0.099	0.117	0.137	0.157	0.183	0.201
35 to <45	0.120 ± 0.020	0.086	0.095	0.105	0.118	0.133	0.147	0.163	0.172	0.119 ± 0.020	0.084	0.094	0.104	0.118	0.132	0.146	0.162	0.170
45 to <65	0.110 ± 0.024	0.072	0.082	0.093	0.108	0.125	0.143	0.162	0.172	0.108 ± 0.023	0.068	0.079	0.092	0.107	0.123	0.139	0.157	0.166
65 to ≤96	0.098 ± 0.025	0.056	0.067	0.079	0.095	0.113	0.131	0.152	0.163	0.086 ± 0.026	0.045	0.055	0.067	0.083	0.102	0.122	0.147	0.159
($l\ m^{-2}\ min^{-1}$)[b]																		
5 to <7	4.43 ± 0.96	2.82	3.26	3.74	4.35	5.03	5.71	6.57	7.01	4.29 ± 0.91	2.76	3.16	3.61	4.21	4.86	5.51	6.31	6.72
7 to <10	4.52 ± 1.18	2.66	3.14	3.66	4.38	5.23	6.12	7.20	7.90	4.26 ± 0.98	2.66	3.08	3.55	4.17	4.85	5.57	6.50	6.93
10 to <16.5	4.88 ± 1.60	2.49	3.02	3.68	4.63	5.82	7.10	8.57	9.46	3.97 ± 1.15	2.17	2.62	3.13	3.82	4.67	5.52	6.60	7.21
16.5 to <25	4.97 ± 0.95	3.25	3.74	4.27	4.94	5.61	6.21	6.87	7.24	4.59 ± 0.79	3.18	3.60	4.03	4.54	5.11	5.62	6.25	6.58
25 to <35	4.56 ± 0.95	3.02	3.42	3.87	4.45	5.13	5.85	6.72	7.19	4.25 ± 0.94	2.65	3.12	3.58	4.16	4.81	5.49	6.31	6.86
35 to <45	4.53 ± 0.70	3.32	3.64	4.01	4.49	4.99	5.47	5.98	6.31	4.25 ± 0.69	3.05	3.39	3.75	4.21	4.72	5.17	5.66	5.93
45 to <65	4.21 ± 0.85	2.83	3.16	3.57	4.11	4.77	5.40	6.06	6.41	3.89 ± 0.79	2.45	2.89	3.34	3.86	4.42	4.94	5.51	5.80
65 to ≤96	3.65 ± 0.90	2.14	2.55	2.98	3.57	4.23	4.86	5.60	5.97	3.08 ± 0.90	1.63	2.00	2.42	2.98	3.65	4.31	5.10	5.53

[a] $Q\alpha = [(TDEE - BEE)/((24 - Sld) \times 60) + (BEE + ECG)/1440] \times H_P \times AVOD\alpha^{-1}$, where H_p = oxygen uptake factor, $AVOD\alpha$ = arteriovenous oxygen content differences (ml of O_2 consumed ml^{-1} of blood). Values for $AVOD\alpha$ are given in Table 1. TDEE, BEE, ECG and Sld are defined in Table 3. [b] $Q\alpha$ ($L\ min^{-1}$) were divided by body weights (Bw) and body surface areas (BSA) in order to obtain values expressed in $l\ kg^{-1}\ min^{-1}$ and $l\ m^{-2}\ min^{-1}$ respectively. [a, b] Values for TDEE, BEE, ECG (kcal per day), Sld (h per day), Bw (kg), BSA (m^2) and, H_P (0.2059 ± 0.0019 l of O_2 $kcal^{-1}$) were taken from Brochu *et al.* (2011). SD = standard deviation.

Table 7. Distribution percentiles of alveolar ventilation rates for aggregate daytime activities of normal-weight individuals aged 5–96 years

Age group (years)	Alveolar ventilation rates[a] Males Mean ± SD	Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th	Females Mean ± SD	Percentiles 2.5nd	10th	25th	50th	75th	90th	97.5th	99th
									(l min^{-1})									
5 to <7	5.14 ± 1.07	3.33	3.83	4.36	5.06	5.82	6.56	7.48	8.02	4.94 ± 1.00	3.25	3.71	4.22	4.86	5.58	6.28	7.13	7.55
7 to <10	6.47 ± 1.58	3.95	4.58	5.31	6.28	7.41	8.63	10.02	10.93	6.24 ± 1.35	3.99	4.59	5.26	6.11	7.07	8.07	9.28	9.89
10 to <16.5	9.84 ± 3.15	5.16	6.19	7.51	9.37	11.67	14.11	17.21	18.81	8.38 ± 2.53	4.45	5.41	6.55	8.05	9.85	11.79	14.27	15.77
16.5 to <25	12.52 ± 3.22	7.38	8.71	10.20	12.11	14.44	16.86	19.76	21.50	10.37 ± 2.47	6.40	7.46	8.58	10.08	11.85	13.64	15.87	17.26
25 to <35	11.52 ± 2.78	7.15	8.27	9.52	11.17	13.18	15.22	17.82	19.62	9.30 ± 2.30	5.48	6.57	7.67	9.06	10.61	12.38	14.59	15.86
35 to <45	11.12 ± 3.26	6.16	7.36	8.76	10.64	13.04	15.49	18.69	20.52	9.29 ± 2.81	5.05	6.08	7.25	8.86	10.87	13.06	15.76	17.58
45 to <65	10.23 ± 2.93	5.68	6.83	8.12	9.83	11.87	14.22	17.12	18.71	8.27 ± 2.39	4.46	5.47	6.53	7.98	9.67	11.48	13.76	15.04
65 to ≤96	8.07 ± 2.58	4.06	5.08	6.20	7.72	9.54	11.53	14.22	15.50	5.99 ± 2.13	2.80	3.54	4.42	5.67	7.22	8.91	10.96	12.17
									(l kg^{-1} min^{-1})[b]									
5 to <7	0.263 ± 0.061	0.163	0.191	0.219	0.257	0.300	0.343	0.398	0.435	0.254 ± 0.059	0.157	0.184	0.212	0.248	0.290	0.334	0.386	0.414
7 to <10	0.248 ± 0.072	0.137	0.165	0.196	0.238	0.289	0.345	0.415	0.464	0.231 ± 0.058	0.138	0.161	0.189	0.224	0.266	0.307	0.361	0.392
10 to <16.5	0.241 ± 0.096	0.106	0.136	0.170	0.223	0.292	0.366	0.477	0.553	0.193 ± 0.068	0.093	0.116	0.143	0.183	0.229	0.285	0.355	0.395
16.5 to <25	0.178 ± 0.048	0.103	0.122	0.143	0.172	0.206	0.244	0.290	0.312	0.173 ± 0.044	0.104	0.122	0.141	0.168	0.199	0.233	0.274	0.299
25 to <35	0.162 ± 0.042	0.097	0.114	0.132	0.156	0.187	0.218	0.259	0.284	0.161 ± 0.044	0.092	0.110	0.129	0.155	0.186	0.219	0.261	0.285
35 to <45	0.160 ± 0.049	0.086	0.104	0.125	0.152	0.188	0.225	0.273	0.300	0.159 ± 0.050	0.084	0.103	0.123	0.151	0.186	0.226	0.273	0.305
45 to <65	0.144 ± 0.043	0.077	0.094	0.112	0.138	0.168	0.201	0.246	0.274	0.141 ± 0.042	0.075	0.092	0.111	0.136	0.166	0.198	0.237	0.266
65 to ≤96	0.119 ± 0.040	0.059	0.074	0.091	0.114	0.141	0.172	0.216	0.237	0.106 ± 0.040	0.047	0.061	0.077	0.100	0.128	0.160	0.200	0.221
									(l m^{-2} min^{-1})[b]									
5 to <7	6.56 ± 1.44	4.15	4.80	5.52	6.43	7.45	8.47	9.73	10.51	6.32 ± 1.36	4.02	4.65	5.33	6.20	7.16	8.14	9.33	10.09
7 to <10	6.70 ± 1.78	3.90	4.62	5.40	6.48	7.74	9.08	10.72	11.86	6.31 ± 1.45	3.92	4.57	5.26	6.16	7.20	8.29	9.51	10.31
10 to <16.5	7.45 ± 2.68	3.54	4.43	5.48	7.03	8.95	11.04	13.82	15.53	6.07 ± 1.96	3.09	3.81	4.63	5.78	7.19	8.68	10.70	11.92
16.5 to <25	6.71 ± 1.76	3.88	4.66	5.43	6.47	7.75	9.05	10.73	11.63	6.19 ± 1.51	3.77	4.42	5.09	6.02	7.10	8.23	9.54	10.46
25 to <35	6.14 ± 1.53	3.73	4.35	5.03	5.94	7.05	8.15	9.66	10.57	5.72 ± 1.47	3.30	3.99	4.66	5.56	6.58	7.67	9.03	9.89
35 to <45	6.03 ± 1.79	3.31	3.97	4.73	5.76	7.06	8.42	10.25	11.23	5.67 ± 1.73	3.02	3.69	4.41	5.41	6.64	7.99	9.65	10.68
45 to <65	5.49 ± 1.61	3.02	3.63	4.32	5.27	6.39	7.63	9.30	10.20	5.07 ± 1.48	2.71	3.34	4.00	4.89	5.96	7.05	8.51	9.35
65 to ≤96	4.46 ± 1.45	2.22	2.79	3.42	4.25	5.27	6.40	7.92	8.75	3.76 ± 1.37	1.73	2.19	2.76	3.56	4.54	5.60	6.96	7.74

[a] $VA\alpha = [(TDEE - BEE)/((24 - Sld) \times 60) + (BEE + ECG)/1440] \times H_P \times VQ\alpha \times (1 - VDphys\alpha/VT\alpha)$, where $VDphys\alpha/VT\alpha$ = ratio of the physiological dead space to the tidal volume, H_P = oxygen uptake factor and $VQ\alpha$ = ventilatory equivalent. Values for $VDphys\alpha/VT\alpha$ (unitless) are given in Table 2. TDEE, BEE, ECG and Sld are defined in Table 3. [b] $VA\alpha$ (l min^{-1}) were divided by body weights (Bw) and body surface areas (BSA) in order to obtain values expressed in l kg^{-1} min^{-1} and l m^{-2} min^{-1} respectively. [a, b] Values for TDEE, BEE, ECG (kcal per day), Sld (h per day), Bw (kg), BSA (m^2), H_P (0.2059 ± 0.0019 l of O_2 kcal^{-1}) and $VQ\alpha$ (unitless) are reported in Brochu *et al.* (2011). SD = standard deviation.

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Table 8. Distribution percentiles of ventilation-perfusion ratios for aggregate daytime activities of normal-weight individuals aged 5 to 96 years

Age group for both genders (years)	Mean ± SD	Ventilation-perfusion ratios[a] (l of alveolar air per l of blood) Percentiles							
		2.5nd	10th	25th	50th	75th	90th	97.5th	99th
5 to <7	1.49 ± 0.12	1.26	1.34	1.40	1.49	1.57	1.64	1.73	1.78
7 to <10	1.49 ± 0.12	1.26	1.34	1.40	1.49	1.57	1.64	1.73	1.78
10 to <16.5	1.53 ± 0.24	1.12	1.24	1.37	1.51	1.68	1.84	2.05	2.16
16.5 to <25	1.36 ± 0.28	0.91	1.03	1.16	1.33	1.52	1.72	1.98	2.14
25 to <35	1.35 ± 0.22	0.98	1.09	1.20	1.34	1.49	1.63	1.82	1.93
35 to <45	1.34 ± 0.36	0.76	0.92	1.08	1.29	1.54	1.82	2.16	2.40
45 to <65	1.31 ± 0.29	0.83	0.97	1.10	1.27	1.48	1.70	1.96	2.11
65 to ≤96	1.22 ± 0.27	0.78	0.91	1.03	1.19	1.38	1.58	1.83	1.98

[a]*VAa/Qa*. Values for *Qa* (l of blood min^{-1}) and *VAa* (l of alveolar air min^{-1}) are given in Tables 6 and 7 respectively.
SD = standard deviation.

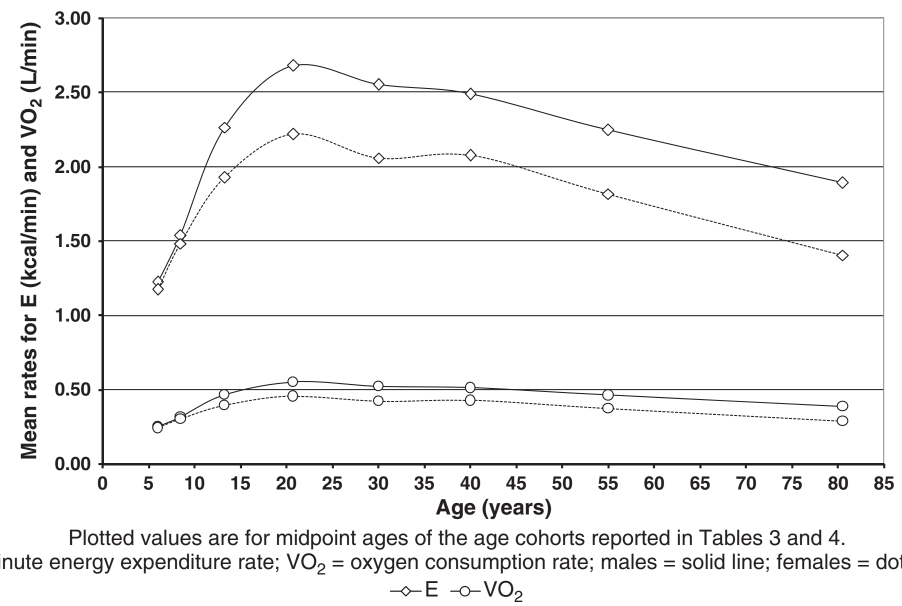

Figure 1. Mean minute energy expenditure (kcal min^{-1}) and oxygen consumption rates (l min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

individual values for *VAa* and VD_{physa}/VTa ratios, which better correspond to normal distributions (data not shown in tables). Values for AVOD*a* associated with VO_2a values were found to vary from 0.059 ± 0.003 to 0.073 ± 0.004 ml of O_2 ml^{-1} of blood (Table 1). Values for VD_{physa}/VTa ratios that were calculated based on simultaneous VD_{physa} and *VTa* measurements for healthy subjects free from cardiac and pulmonary diseases (Table 2) correspond to *VAa/VEa* ratios (i.e. 1-VD_{physa}/VTa) varying from 0.619 ± 0.018 to 0.706 ± 0.032.

A 25% reduction in sleep duration for 60% of overweight/obese children, 35% of overweight adults and 55% of their obese counterparts decreased VO_2a, Q*a*, *VEa* and *VAa* values of the entire cohorts by only 0.5% in boys, 0.6–0.7% in girls and 1.2 and 1.0% in adult males and females, respectively, while *VA*/Q*a* ratios were not altered (data not presented in tables).

Maximum mean errors associated with H_P (−1%), BEE (+2%), ECG and TDEE values (+3.3%) resulted, when combined, in increasing *Ea*, VO_2a, Q*a*, *VEa* and *VAa* values by −2.8 to +3.9%. An inverse scenario was observed with minimum mean errors for H_P (-2%), BEE (+1), ECG and TDEE (−1.0%) values, affecting *Ea*, VO_2a, Q*a*, *VEa* and *VAa* values by −1.9 to +4.0%. Variations of H_P, BEE, TDEE and ECG values did not alter the magnitude of the *VAa*/Q*a* ratios (data not given in tables).

DISCUSSION

The respiratory and cardiovascular parameters determined in the present study are consistent with the range of published values. *VAa*/Q*a* ratios reported in this study (or *VAa* and Q*a* values) are in agreement with the known values in subjects in the upright

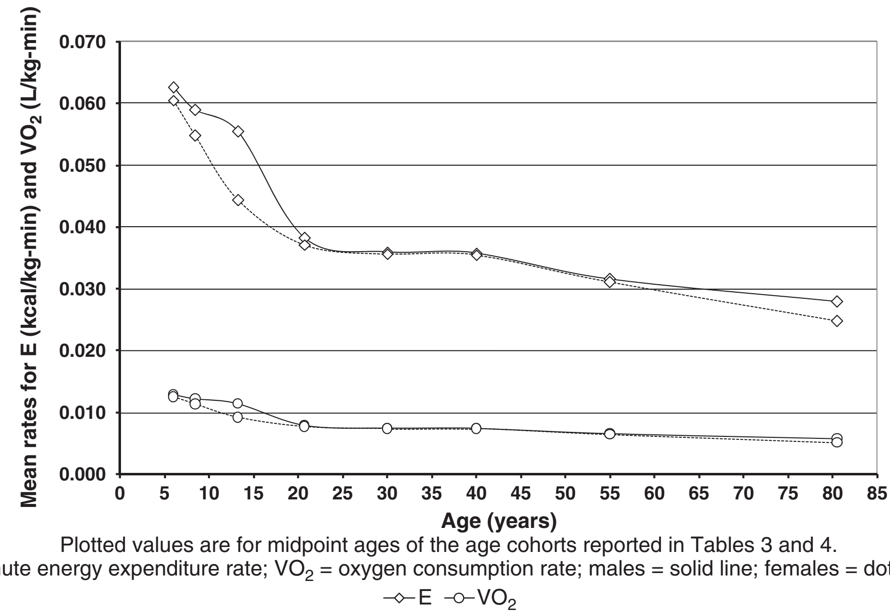

Figure 2. Mean minute energy expenditure (kcal kg^{-1} min^{-1}) and oxygen consumption rates (l kg^{-1} min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

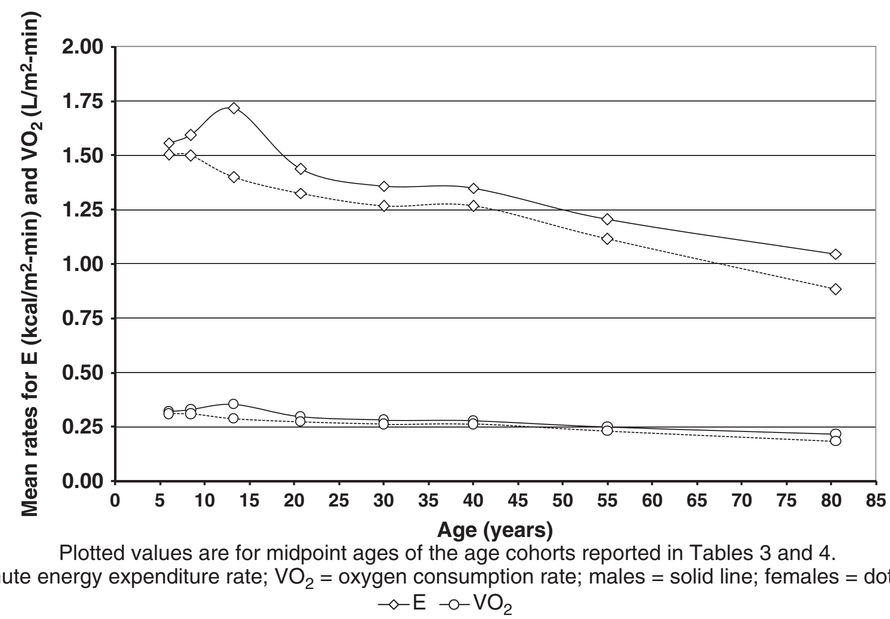

Figure 3. Mean minute energy expenditure (kcal m^{-2} min^{-1}) and oxygen consumption rates (l m^{-2} min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

position when their experimental VO_2 demands are within the span of VO_2a values. This concordance is reflective of the adequacy of the processes and sets of input parameters used for the determination of *VAa* and Q*a* values (i.e. *VEa*, VD_{physa}/VTa and VO_2a, AVOD*a* respectively), and of course for the calculation of *VEa* (i.e. *Ea*, H_P, *VQa*) as well as VO_2a (i.e. *Ea*, H_P). For instance, mean and individual *VA/Q* ratios reported in the literature for resting adults range from 0.74 ± 0.09 to 0.87 ± 0.28 ($n = 77$) and from 0.58 to 1.13 ($n = 20$), respectively (Farhi and Rahn, 1955; West and Dollery, 1960; West, 1962; Lenfant, 1963; Ayres *et al.*, 1964; Johnson and Miller, 1968; West *et al.*, 1974; Zwart *et al.*, 1976; Frostell *et al.*, 1983; Rhodes *et al.*, 1989; Yem *et al.*, 2006). The span of these ratios is in accordance with values of the gap between the 2.5th and 10th percentile *VAa*/Q*a* ratios varying from 0.78 to 1.09 for individuals aged 16.5–<96 years with associated VO_2a values (0.157–0.426 l min^{-1}); this matches well with typical published VO_2 demands (0.236–0.454 l min^{-1}) for resting subjects ($n = 46$) aged 19–81 years (Damato *et al.*, 1966; Bachofen *et al.*, 1973). Spans of *VAa*/Q*a* ratios from the 2.5th to 99th percentile in individuals aged 16.5–<25 years and from 10th

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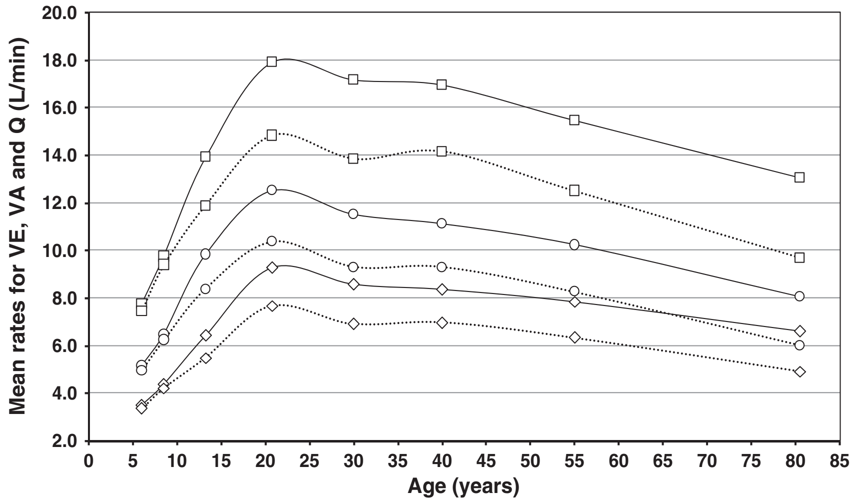

Figure 4. Mean minute ventilation rates, alveolar ventilation rates and cardiac outputs (l min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

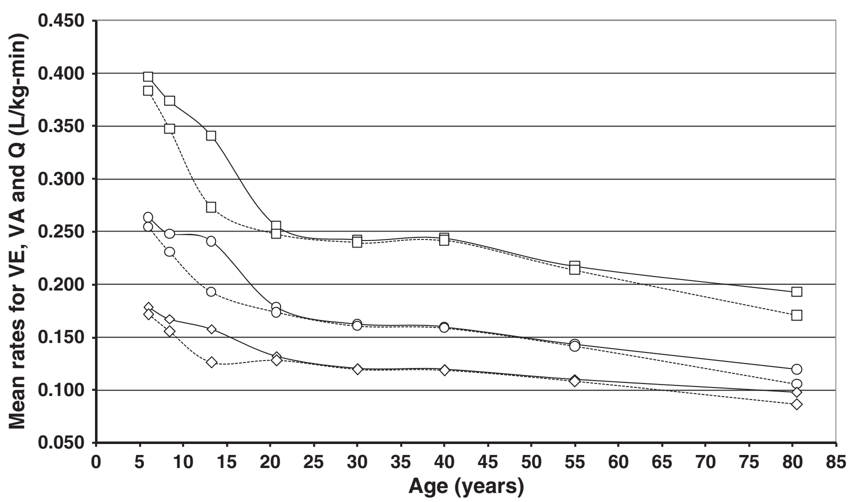

Figure 5. Mean minute ventilation rates, alveolar ventilation rates and cardiac outputs (l kg^{-1} min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

to 99th percentile in those 35–<45 years of age range from 0.91 to 2.14 (*VEa* from 9.22 to 30.41) and from 0.92 to 2.40 (*VEa* from 9.28 to 31.39 l min^{-1}) respectively. By comparison, *VA*/*Q* ratios vary from 0.90 to 2.45 based on *VA* and *Q* values measured in females aged 20–30 years ($n = 8$) inhaling about the same volume of air varying from 9 to 31 l min^{-1} (Olfert *et al.*, 2004). These 99th percentile *VAa*/*Qa* ratios of 2.14 and 2.40 for *VEa* of 30.41 and 31.39 l min^{-1}, respectively, are also consistent with the higher value of *VA*/*Q* ratio of 2.61 resulting from measurements in men aged 20–30 years ($n = 7$) when they were performing activities requiring the higher *VE* value of 38.2 l min^{-1} (Olfert *et al.*, 2004). The 99th percentile *VAa*/*Qa* ratio of 1.93 for VO_2a ranging from 0.648–0.796 l min^{-1} in individuals aged 25–<35 year is confirmed by *VA*/*Q* ratios ranging from 2.00 to 2.01 based on simultaneous *VA* and *Q* measurements in females aged 23.6–30.2 years ($n = 17$) by Hopkins *et al.* (2000) during slightly higher VO_2 demands (0.79–0.83 l min^{-1}). No published *VAa*/*Qa* ratio is available for older individuals. However, *VEa* values used to calculate *VAa* values as well as *Qa* values for older individuals are in agreement with published values. Spans of *VEa* values in males and females aged 45–<65 years between the 2.5th and 99th percentile range from 6.78 to 28.06 l min^{-1} (VO_2a from 0.240 to 0.671 l min^{-1}), while those in males 65–96 years old vary from 4.52 to 25.16 l min^{-1} (VO_2a from 0.157 to 0.611 l min^{-1}). Such *VEa* values are in

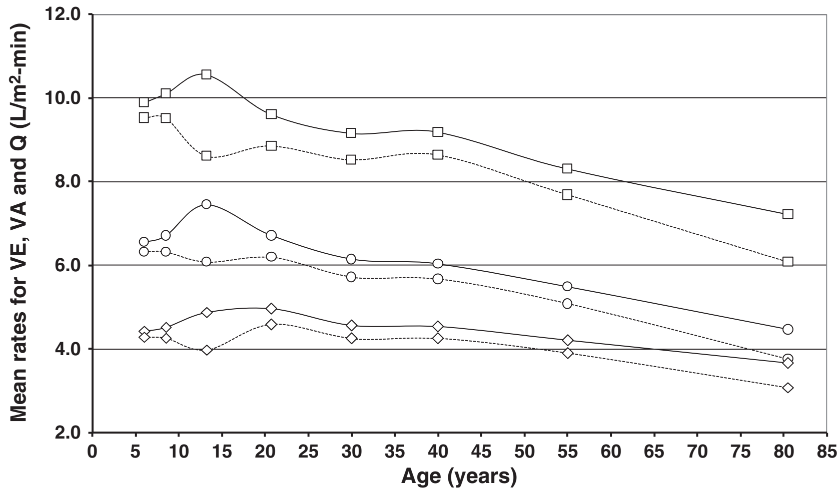

Figure 6. Mean minute ventilation rates, alveolar ventilation rates and cardiac outputs (l m^{-2} min^{-1}) for aggregate daytime activities of normal-weight males and females as a function of age.

accordance with published *VE* values varying from 5.6 to 32.3 l min^{-1} (VO_2 from 0.236 to 0.797 l min^{-1}) in adults aged 45–63 years ($n = 40$) and from 5.71 to 25.1 l min^{-1} (VO_2 from 0.167 to 0.673 l min^{-1}) in males 65–91 years old ($n = 29$) respectively (Robinson, 1938; Cohn *et al.*, 1954; Tenney and Miller, 1956; Raine and Bishop, 1963; Damato *et al.*, 1966; Bachofen *et al.*, 1973; Nery *et al.*, 1982; Frostell *et al.*, 1983). The span between the 25th and 99th percentile Q*α* values for individuals aged 45–96 years ranging from 3.89 to 11.65 l min^{-1} ($VO_2\alpha$ from 0.230 to 0.671 l min^{-1}) agrees with published values ranging from 3.7 to 12.30 l min^{-1} (VO_2 from 0.202 to 0.647 l min^{-1}) for subjects aged 45–73 years (Reeves *et al.*, 1961; Damato *et al.*, 1966; Emirgil *et al.*, 1967; McGuire *et al.*, 2001; $n = 48$).

Regarding children aged 10–<16.5 years, the 2.5th percentile *VAα*/Q*α* ratio of 1.12 ($VO_2\alpha$ from 0.229 to 0.266 l min^{-1}) is in agreement with those varying from 1.07 to 1.17 estimated on the basis of ratios varying from 0.85 to 0.93 for boys aged 11 to 13 years ($n = 9$) in the supine position during VO_2 demands ranging from 0.24 to 0.25 l min^{-1} (Koch and Eriksson, 1973). The latter ratios were increased by 25.3% in order to compensate for the proportional decrease of blood flow that is observed when subjects change from a supine to an upright position (Reeves *et al.*, 1961; Damato *et al.*, 1966; Hossack and Bruce, 1982; Gisolf *et al.*, 2003). Our 99th percentile *VAα*/Q*α* ratio value of 2.16 for the same age groups ($VO_2\alpha$ from 0.681 to 0.806 l min^{-1}) is consistent with higher *VA*/*Q* ratio of 2.49 measured for boys ($n = 9$) in the sitting position during much higher VO_2 requirements of 1.14 l min^{-1} (Koch and Eriksson, 1973). The gap between these lower and upper limits of *VA*/*Q* ratios varying from 1.07 to 2.49 based on data reported in Koch and Eriksson (1973) confirms the magnitude of the span between the 2.5th and 99th percentile *VAα*/Q*α* ratios ranging from 1.12 to 2.16 in children aged 10–<16.5 years. The magnitudes of *VAα* and Q*α* values for younger children are confirmed by published measurements. For instance, the span between the 25th and 90th percentile *VAα* values ranges from 5.26 to 8.63 ($VO_2\alpha$ from 0.259 to 0.417 l min^{-1}) in children aged 7–<10 years. By comparison, *VA* values varying from 5.03 to 9.03 l min^{-1} have been measured in those aged 6–17 years ($n = 56$) during comparable VO_2 demands ranging from 0.262 to 0.389 l min^{-1} (Zapletal *et al.*, 1987). The 97.5th percentile Q*α* values of 6.73 l min^{-1} in boys and 6.23 l min^{-1} in girls aged 7–<10 years for $VO_2\alpha$ of 0.487 and 0.446 l min^{-1}, respectively, are also in accordance with mean values of 6.8 l min^{-1} in males ($n = 12$) and 6.60 l min^{-1} in females ($n = 12$) aged 7–9 years measured during light activities with VO_2 demands of 0.55 and 0.51 l min^{-1} respectively (Turley and Wilmore, 1997a).

As expected, mean *VAα*/Q*α* ratios in children aged 5–<16.5 years (1.49 ± 0.12 to 1.53 ± 0.24) are higher than those for older individuals 16.5–96 years old (1.22 ± 0.27 to 1.36 ± 0.28). In response to higher oxygen demands associated with higher energy expenditures in children aged 5–<16.5 years (0.044 ± 0.014 to 0.063 ± 0.014 kcal kg^{-1} min^{-1}, 1.40 ± 0.40 to 1.72 ± 0.56 kcal m^{-2} min^{-1}), when compared with lower oxygen demands in older individuals aged 16.5–96 years (0.025 ± 0.007 to 0.038 ± 0.007 kcal kg^{-1} min^{-1}, 0.88 ± 0.25–1.44 ± 0.25 kcal m^{-2} min^{-1}), *VA* (and thus *VE*) values increase in order to sustain adequate oxygen blood concentrations, while the *Q* values rise in order to increase oxygen transport to all body tissues. Higher oxygen uptakes in children compared with those in older individuals are reflected by higher number of alveoli per unit of body weight and body surface area. For instance, the number of alveoli determined in children 4 and 8 years of age is 15.86 and 11.20×10^6 alveoli kg^{-1}, or 383.6 and 304.4×10^6 alveoli m^{-2} respectively, compared with much lower values in adults: 3.84×10^6 alveoli kg^{-1} or 155.8×10^6 alveoli m^{-2} (Dunnill, 1962). These values are consistent with those reported by Davies and Reid (1970) as well as Angus and Thurlbeck (1972).

Thus, alveolar ventilation rates must maintain a relatively high level of alveolar and arterial oxygen partial pressure in order to compensate for temporary biochemical differences that are observed in children aged 5–<16.5 years compared with older individuals. Lower blood hemoglobin concentrations and slightly higher concentrations of 2,3-diphosphoglycerate are observed in children 5–<10 years old compared with those aged 10–<16.5 years (Motoyama *et al.*, 1990). Higher concentrations of 2,3-diphosphoglycerate in red cells increase the oxygen unloading from hemoglobin at the tissue level (Oski and Delivoria-Papadopoulos, 1970; Card and Brain, 1973; Oski, 1973, Motoyama *et al.*, 1974). Mean hemoglobin levels for children aged 2–5, 6–8, 10–12 and 14–16 years are 11.9 ± 1.2 (n = 22), 12.6 ± 0.8 (n = 41), 13.2 ± 0.9 (n = 54) and 14.4 ± 1.4 g dl^{-1} (n = 34) in boys and 12.4 ± 0.9 (n = 20), 12.7 ± 1.0 (n = 10), 13.2 ± 1.0 (n = 29) and 13.4 ± 1.2 g dl^{-1} (n = 15) in girls, respectively (Spurr *et al.*, 1992). These values, which are in agreement with other blood hemoglobin concentrations varying from 12.99 ± 0.31 to 13.9 ± 1.3 g dl^{-1} (n = 186) for children 7–13.7 years of age (Åstrand, 1952; Eriksson *et al.*, 1971; Koch and Eriksson, 1973; Turley and Wilmore, 1997a, b; Obert *et al.*, 2003; Vinet *et al.*, 2003), are lower than those for adults aged 18–89 years (n = 504) ranging from 13.00 ± 1.25 to 15.9 ± 1.2 g dl^{-1} (Rotta *et al.*, 1956; Tenney and Miller, 1956; Åstrand *et al.*, 1964; Ekblom *et al.*, 1968; Holmér *et al.*, 1974; Kanstrup and Ekblom, 1982; Bebout *et al.*, 1989; Stringer *et al.*, 1997; Proctor *et al.*, 1998a, b, 2003; Sun *et al.*, 2000; Poole *et al.*, 2002; Mourtzakis *et al.*, 2004; Beck *et al.*, 2006). Overall, immature mechanisms for oxygen transport to body tissues with higher energy expenditures in children 5–<16.5 years old provide a reasonable explanation for the unique values of *VA* and *Q* specific to this age group.

The magnitude of inter-individual variability of 8.4 for cardiac output and 13.4 for alveolar ventilation rate was calculated as the ratio of the highest 99th percentiles of 0.330 and 0.553 l kg^{-1} per day (Tables 6 and 7) to the lowest 1st percentiles of 0.039 and 0.041 l kg^{-1} per day, respectively (data not shown in tables) in males and females aged 5–96 years. The magnitude of human variability in *Q* and *VA* values, as reflected by the lowest 50th percentiles of 0.084 and 0.100 l kg^{-1} per day (Tables 6 and 7) and the highest 95th percentiles of 0.262 and 0.413 l kg^{-1} per day (data not shown in tables) correspond to factors of 3.1 and 4.1, respectively. The impact of such inter-individual variability in *Q* (i.e. 3.1–8.4) and *VA* values (i.e. 4.1–13.4) should be assessed along with the variability in other pharmacokinetic determinants, in order to evaluate the adequacy of the default uncertainty factor or the human kinetic adjustment factor currently used in health risk assessment (Renwick, 2000; World Health Organization, 2005).

CONCLUSION

The present study provides a complete and original set of key respiratory and cardiovascular parameters (i.e. *Ea*, AVOD*a* VO_2a, *VEa*, Q*a*, *VAa*, values and VD_{physa}/VTa, *VAa*/Q*a* ratios), with their distributions, for healthy normal-weight males and females aged 5–96 years old during their aggregate daytime activities. As done by Brochu *et al.* (2011) for the selection of input literature data when calculating H_P and *VQa* values, solely data measured in subjects in the upright position during VO_2 demands that were within the span of VO_2a^* values were used in this study. Such a procedure assures that data included in the calculation processes of VO_2a, *VEa*, Q*a*, *VAa*, values and *VAa*/Q*a* ratios adequately describe daytime activities for individuals of different age groups. The fact that the spans of VO_2a values per age group appear to be in agreement with those for VO_2a^* provides added value to this approach.

Determination of energy expenditures during aggregate daytime activities (i.e. *Ea*) for each age group by subtracting published BEE from TDEE values that are measured for the same subjects by the DLW method is unique. Indirect calorimetry measurements (n = 902) in normal-weight males and females and disappearance rates of oral doses of water isotopes (^2H_2O and $H_2{}^{18}O$) in urine for an aggregate period of over 14 000 days were used for the calculation of *Ea* values. In addition, the accuracy of VO_2a, *VEa*, Q*a*, *VAa*, values expressed in l min^{-1}, l kg^{-1} min^{-1} as well as l m^{-2} min^{-1} and *VAa*/Q*a* ratios is enhanced by the facts that: (1) the weight and height, as well as the BEE and TDEE values used in the calculation processes, were available for each subject when conducting the DLW method; (2) each TDEE value systematically encompasses voluntary and involuntary energy expended in unrestrained free-living subjects each minute of the day, 24 h per day, on a daily basis during 7–21 days; and (3) in the worst case scenario, simultaneous extreme mean errors for H_P (−2 to −1%), BEE (+1 to +2%) and TDEE (−1.0 to +3.3%) values only affect *Ea*, VO_2a, Q*a*, *VEa*, *VAa* values by −2.8 to +4.0%.

The absorption rates of inhaled gases and vapors of xenobiotics with high or low blood/gas phase solubility ratios are increased by higher *VA* or *Q* values respectively (Klaassen, 1996). In the present study, generally higher 2.5nd to 99th percentile *VEa* (0.132–0.774 l kg^{-1} min^{-1}, 4.42–21.69 l m^{-2} min^{-1}), *VAa* (0.093–0.553 l kg^{-1} min^{-1}, 3.09–15.53 l m^{-2} min^{-1}) and Q*a* values (0.065–0.330 l kg^{-1} min^{-1}, 2.17–9.46 l m^{-2} min^{-1}), as well as *VAa*/Q*a* ratios (1.12–2.16) were found in normal-weight children 5–<16.5 years of age when compared with older individuals (*VEa* 0.076–0.461 l kg^{-1} min^{-1}, 2.80–16.99 l m^{-2} min^{-1}; Q*a* 0.045–0.201 l kg^{-1} min^{-1} and 1.63–7.24 l m^{-2} min^{-1}; *VAa* 0.047–0.312 l kg^{-1} min^{-1} and 1.73–11.63 l m^{-2} min^{-1}; *VAa*/Q*a* ratios 0.78–2.40). Therefore, all factors being equal, the age-related differences in the respiratory rates and cardiac output can have a direct effect on the intake and uptake of inhaled gases and vapors, notably liposoluble air pollutants by the respiratory tract in younger individuals.

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Declaration of Interest

The authors declare that there are no conflicts of interest.

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